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Stawski

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(54) **COMPOSITE STRUCTURE AND METHOD**

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USPC *264/511*; *156/287*, *382*
See application file for complete search history.

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Primary Examiner — Alexander Thomas

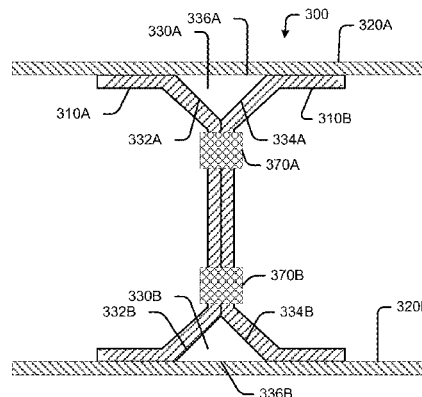
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(57)

ABSTRACT

In one embodiment a method to form a composite part comprises joining a first structural element and a second element to form a fillet at an intersection of the first structural element and the second element, positioning an inflatable radius filler in the fillet, positioning the composite part in a vacuum chamber, venting the inflatable radius filler to an environment external to vacuum chamber, drawing a vacuum in the vacuum chamber, and curing the composite part. Other embodiments may be described.

20 Claims, 5 Drawing Sheets



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B29L 31/30 (2006.01)

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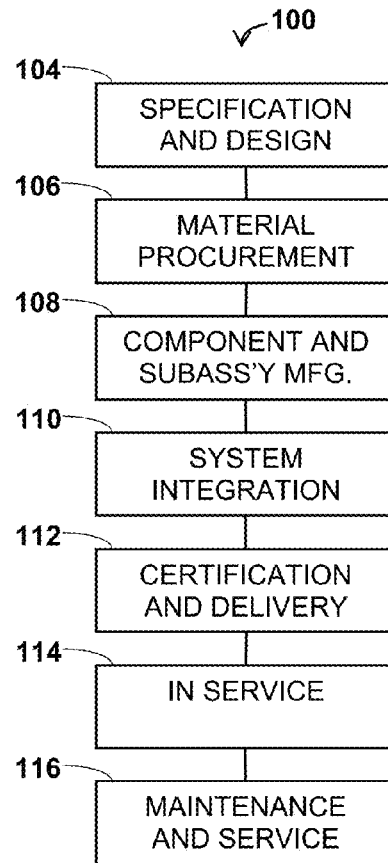


FIG. 1

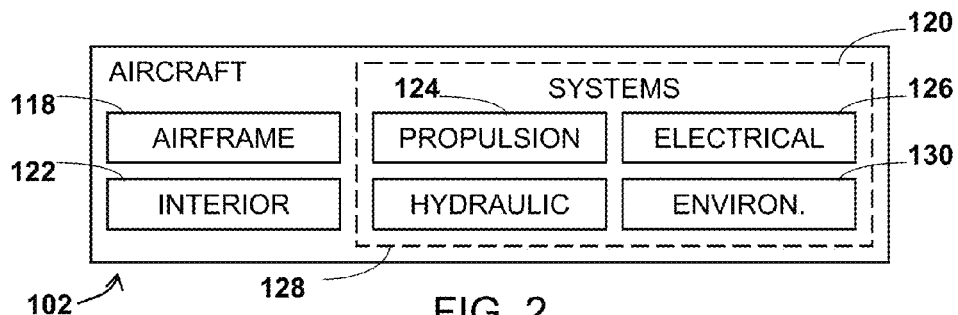


FIG. 2

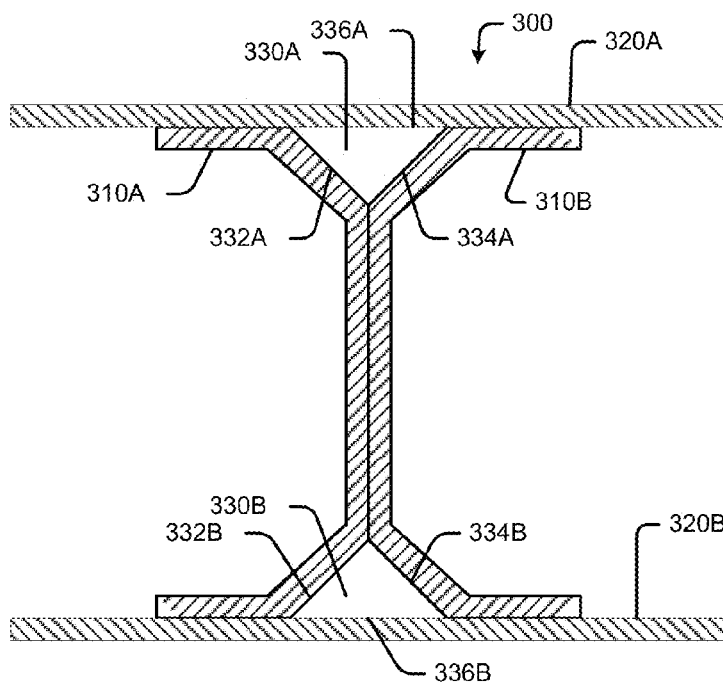


FIG. 3A

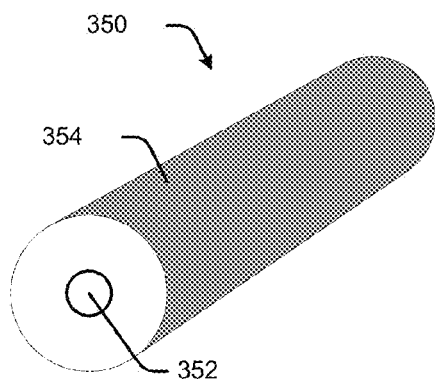


FIG. 3B

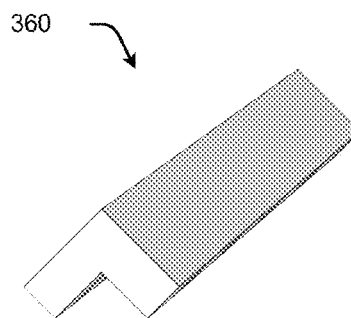


FIG. 3C

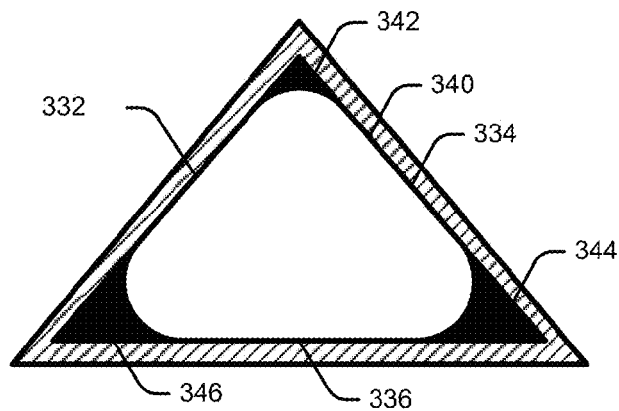


FIG. 3D

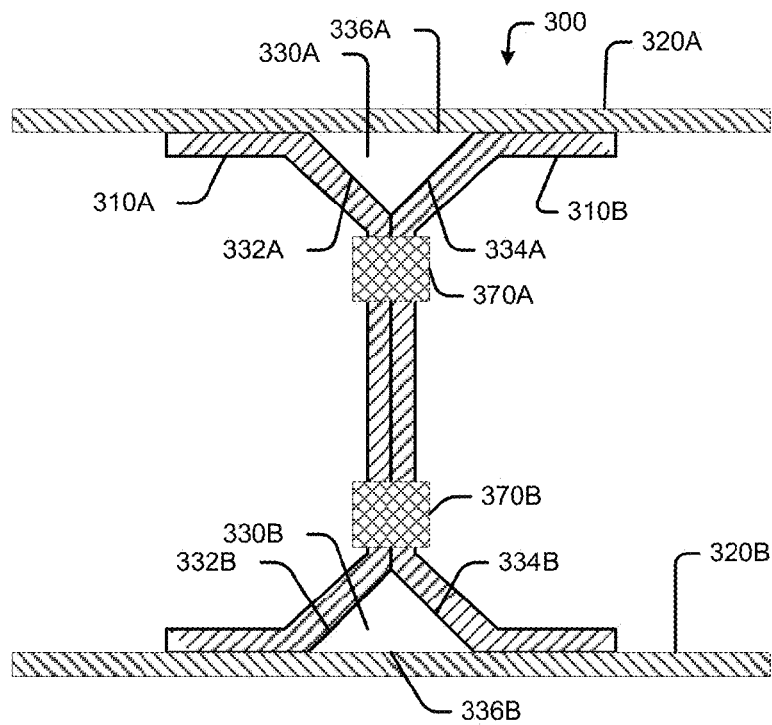


FIG. 3E

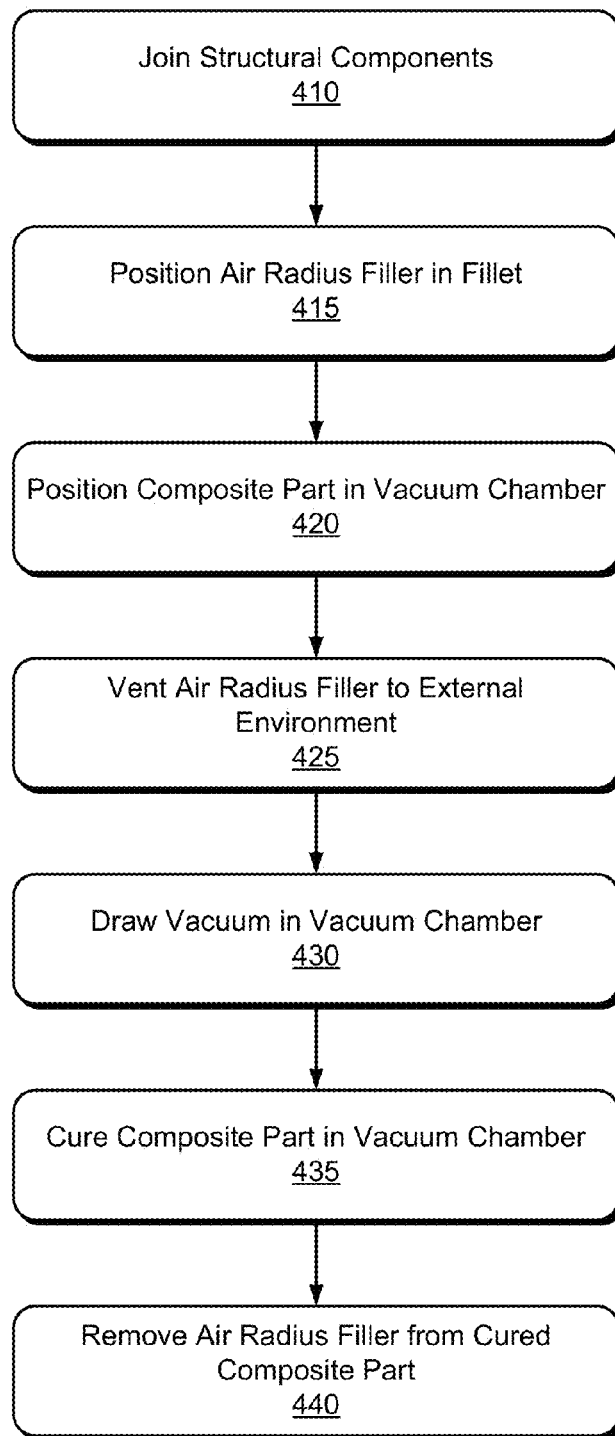


FIG. 4

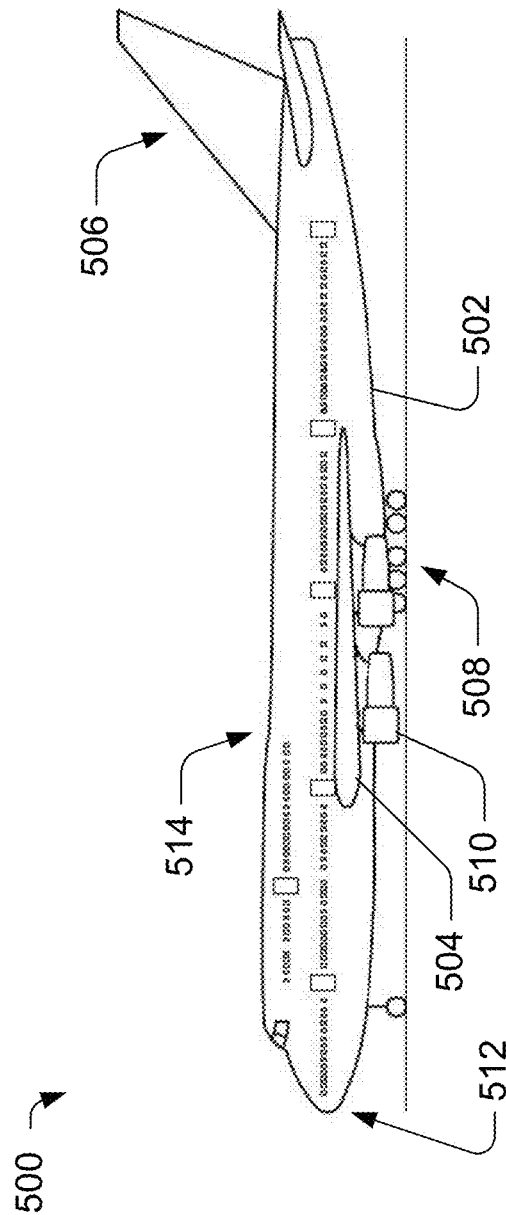


Fig. 5

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COMPOSITE STRUCTURE AND METHOD

RELATED APPLICATIONS

None.

BACKGROUND

The subject matter described herein relates to manufacturing techniques and more particularly to techniques to form a T-shaped or I-shaped composite structure which includes an air gap in a region which would normally contain a radius filler.

Composite structures are used in various manufacturing and construction operations. By way of example, various structural components of aircraft may be formed from composite materials. Composite materials which are incorporated into structures that form a T-shaped or I-shaped cross section, e.g., beams or flanges, typically form a fillet at the intersection of the structures. In conventional manufacturing techniques these fillets are filled with a compound commonly referred to as a radius filler. In some circumstances the use of radius fillers creates structural issues in completed parts.

Accordingly, composite structures and methods to make the same may find utility, e.g., in the construction of vehicles such as aircraft or watercraft.

SUMMARY

In one example, a method to form a composite part comprises joining a first structural element and a second element to form a fillet at an intersection of the first structural element and the second element, positioning an inflatable radius filler in the fillet, positioning the composite part in a vacuum chamber, venting the inflatable radius filler to an environment external to vacuum chamber, drawing a vacuum in the vacuum chamber, and curing the composite part.

In another example, a composite part comprises a first structural element and a second element formed from a composite material and joined at an intersection to define a fillet at the intersection and an inflatable radius filler positioned in the fillet.

In another example, a composite part comprises a first structural element and a second element formed from a composite material and joined at an intersection to define a fillet at the intersection, and an air radius in the fillet.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of methods and systems in accordance with the teachings of the present disclosure are described in detail below with reference to the following drawings.

FIG. 1 is a flow diagram of aircraft production and service methodology, according to embodiments.

FIG. 2 is a block diagram of an aircraft, according to embodiments.

FIG. 3A is a side view of composite structure, according to embodiments.

FIG. 3B is a perspective view of an air radius filler, according to embodiments.

FIG. 3C is a perspective view of a bag carrier, according to embodiments.

FIG. 3D is a side view of fillet, according to embodiments.

FIG. 3E is a side view of composite structure, according to embodiments.

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FIG. 4 is a flowchart illustrating operations in a method to install a wiring harness in a structure, according to embodiments.

FIG. 5 is a schematic illustration of an aircraft, according to embodiments.

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of various embodiments. However, it will be understood by those skilled in the art that the various embodiments may be practiced without the specific details. In other instances, well-known methods, procedures, components, and circuits have not been illustrated or described in detail so as not to obscure the particular embodiments.

As described herein, composite structures may be assembled into structural components for use in a larger structure such as an aircraft, a space vehicle, or a waterborne vehicle. By way of example, aircraft structures such as wings and tails commonly include structural components formed from composite materials. Embodiments described herein allow composite structures to be assembled into T-shaped or I-shaped components without the use of radius fillers, thereby increasing the efficiency of the manufacturing process and allowing for lightweight, strong composite components.

Referring more particularly to the drawings, embodiments of the disclosure may be described in the context of an aircraft manufacturing and service method **100** as shown in FIG. 1 and an aircraft **102** as shown in FIG. 2. During pre-production, exemplary method **100** may include specification and design **104** of the aircraft **102** and material procurement **106**. During production, component and subassembly manufacturing **108** and system integration **110** of the aircraft **102** takes place. Thereafter, the aircraft **102** may go through certification and delivery **112** in order to be placed in service **114**. While in service by a customer, the aircraft **102** is scheduled for routine maintenance and service **116** (which may also include modification, reconfiguration, refurbishment, and so on).

Each of the processes of method **100** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on. As shown in FIG. 2, the aircraft **102** produced by exemplary method **100** may include an airframe **118** with a plurality of systems **120** and an interior **122**. Examples of high-level systems **120** include one or more of a propulsion system **124**, an electrical system **126**, a hydraulic system **126**, and an environmental system **130**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during any one or more of the stages of the production and service method **100**. For example, components or subassemblies corresponding to production process **108** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **102** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **108** and **110**, for example, by sub-

stantially expediting assembly of or reducing the cost of an aircraft **102**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **102** is in service, for example and without limitation, to maintenance and service **116**.

FIGS. **3A-3D** are schematic illustrations of composite part **300**, according to embodiments. Referring to FIGS. **3A-3D**, in some embodiments, a composite part **300** comprises first structural elements **310A** and **310B**, which may be referred to collectively by reference numeral **310** and second structural elements **320A** and **320B**, which may be referred to collectively by reference numeral **320**.

First structural elements **310** and second structural elements **320** may be formed from a fiber-reinforced composite material such as fiberglass, carbon fiber, Kevlar, or the like bonded by a resin such as an epoxy resin or the like. First structural elements **310** and second structural elements **320** may include one or more layers of a reinforcing metal, e.g., aluminum, titanium, or steel.

In the embodiment depicted in FIG. **3A** the first structural elements **310** and second structural elements **320** are joined at an intersections to define fillets **330A** and **330B**, which may be referred to collectively by reference numeral **330**, at the intersections. The first structural elements **310** have a C-shaped cross section and are arranged in opposing orientations such that the fillets **330** are substantially triangular in shape. Fillet **330A** has a first side **332A**, a second side **334A** and a third side **336A**. Similarly, fillet **330B** has a first side **332B**, a second side **334B** and a third side **336B**. One skilled in the art will recognize that the shape of the fillets **330** is a function of the shape of the first structural elements **310**. The side walls **332**, **334**, **336** may be straight or curved, depending upon the shape of the first structural elements. By way of example, in the embodiment depicted in Fig. the fillet is in the form of a triangle having corners which measure approximately 45°-45°-90°. One skilled in the art will recognize that other measurements may be useful. Further, although the composite part **300** has two second structural elements **320** to present an I-shaped cross section, one skilled in the art will recognize that in some embodiments the first structural elements **310** may be secured to a single second structural element **320** to present a T-shaped cross section.

In various embodiments the composite part **300** may be a structural component of an aircraft. Examples of such components include a wing box, a control surfaces, wing, skins, fuselages, doors, or the like.

As described above, in conventional practice fillets **330** have been filled with a structural material commonly referred to in the art as a radius filler. In some circumstances it may be advantageous to manufacture the composite part **300** without a radius filler disposed in the fillet(s) **330**. Techniques to manufacture a composite part **300** without a radius filler will be explained with reference to FIGS. **3A-3C** and FIG. **4**.

FIG. **4** is a flowchart illustrating operations in a method to manufacture a composite part **300** without a radius filler, according to embodiments. Referring to FIG. **4**, at operation **410** the structural components are joined to define a shape such as the shape illustrated in FIG. **3A**, such that the first structural elements **310** define beams and the second structural components define panels which are supported by the beams. In practice, a composite part **300** may comprise numerous beams. An adhesive resin may be applied to the structural elements **310**, **320**. Further, one or more clamps may be applied to the secure the structural elements **310**, **320**.

At operation **415** an inflatable radius filler **350** is positioned in the fillet. FIG. **3B** is a schematic illustration of an inflatable radius filler in accordance with embodiments. Referring to

FIG. **3B**, in some embodiments an inflatable radius filler **350** may comprise a vacuum bag **354** formed from a suitable polymer material such as nylon. The vacuum bag **354** may be expandable to form to the sides **332**, **334**, **336** of the fillets **330**. The vacuum bag **354** may further comprise a vent **352** which allows the vacuum bag **354** to be vented to an external environment.

In some embodiments at least one bag carrier may be positioned in the vacuum bag **354**. One example of a bag carrier **360** is depicted in FIG. **3C**. Referring to FIG. **3C**, in some embodiments the bag carrier **360** may be embodied as a metal bracket having a V-shaped cross section such that the bag carrier **360** conforms to portions of at least to of the sides **332**, **334** of a fillet **330**. In use, the bag carrier **360** may be positioned in the vacuum bag **354**. In some embodiments the bag carrier **360** may be wrapped in a fabric before it is positioned in the bag carrier in order to impart a larger radius to the corners of the fillet **330**, thereby reducing the likelihood of cracking or splitting of the laminate at the corners of the fillet **330**.

In alternate embodiments the inflatable radius filler **350** may be implemented as tube formed from a deformable material, e.g., a suitable polymer or rubber. The tube may be cylindrical in shape, as depicted in FIG. **3B**, or may be formed such that the tube is triangular in shape to correspond to the triangular cross section of the fillets **330**.

At operation **420** the composite part **300** is positioned in a vacuum chamber. By way of example, in some embodiments the vacuum chamber may be embodied as a second vacuum bag which is sufficiently large to hold the entire assembly of structural components. The vacuum chamber **300** may further comprise an autoclave which has an integrated vacuum bag.

At operation **425** the inflatable radius filler **350** is vented to an external environment. By way of example in some embodiments the vent **352** of the inflatable radius filler **350** may be placed in fluid communication with the ambient environment, e.g., by coupling a tube to the vent **352** and extending the tube to the ambient environment.

At operation **430** a vacuum is drawn in the vacuum chamber. As used herein the term vacuum should be construed to mean that the ambient pressure of the gas in the vacuum chamber is reduced to a level below the air pressure of the ambient environment. As used here, the term vacuum should not be construed to require the forming of a perfect vacuum in the vacuum chamber. A vacuum may be drawn by drawing the gas from the vacuum chamber using a pump or the like.

Because the inflatable radius filler **350** is vented to the ambient environment the inflatable radius filler **350** will maintain an internal pressure that corresponds approximately to the ambient environment. Thus, as a vacuum is drawn in the vacuum chamber the inflatable radius filler **350** will expand to occupy the space defined by the fillet(s) **330**. The expansion of the inflatable radius filler **350** in the fillet(s) **330** applies a uniform cure pressure each of the sides **332**, **334**, **336** of the fillet(s) **330**, thereby reducing the risk of ply distortion and voids in the layers of the composite structures **310**, **320**.

At operation **435** the composite part **300** is cured in the vacuum chamber. In some embodiments curing the composite part **300** may comprise heating the composite part to a temperature at which the resin and/or any adhesive used to form the composite part **300** will cure. In addition, the composite part **300** may be subjected to pressure. The specific temperature and pressure applied to the composite part **300** may be a function of the materials from which the composite part is constructed. By way of example, in composite materials used in the aerospace industry are commonly heated to a

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temperature range between 30 degrees centigrade and 200 degrees centigrade and are subjected to pressures between 15 and 100 psi.

At operation **440** the inflatable radius filler **350** is removed from the cured composite part **300** to provide a cured composite part **300** comprising a first structural element **310** and a second element **320** formed from a composite material and joined at an intersection to define a fillet at the intersection, and an air radius in the fillet **330**.

As illustrated in FIG. 3D, in some embodiments the fillet **330** may be provided with a reinforcement member **340** which binds the respective walls **332** of the fillet **330** to one another. The reinforcement member **340** may be formed from fabric material which may be impregnated with an epoxy resin such that during the curing process the fabric material cures to the walls **332** of the fillet **330**. In such embodiments the reinforcement member **340** helps to absorb stress and strain on the structural components that define the fillet **330**. In addition, the resin softens the inner radii of the corners **342**, **344**, **346** of the fillet **330**. Both of these factors reduce the likelihood of cracking or splitting the composite materials at the corners **342**, **344**, **346** of the fillet **330**.

By way of example and not limitation, in some embodiments the vacuum bag **354** may be wrapped in a composite ply material such that, when cured, the composite ply material forms the reinforcement member **340**. The reinforcement member **340** may be formed from the same composite material as the structural elements **310**, **320** such that the composite ply material which forms the reinforcement member **340** has an elastic modulus which is approximately the same as the elastic modulus of the structural components **310**, **320**. The particular number of layers of composite ply material used to wrap the vacuum bag **354** is not critical. In some embodiments the vacuum bag **354** may be wrapped with 1-5 layers of composite ply material.

Thus, described herein are methods to form a composite part which includes one or more fillets **330** that include a hollow aperture, rather than a radius filler. In some embodiments the fillet **330** may be left completely hollow. In other embodiments the fillet **330** may include a reinforcement member **340** formed from one or more layers of composite ply material. In use, the fillet **330** may be used as a conduit through which wiring, cables, fluid lines, or the like may extend. Because the fillet **330** is a confined space, there may be no need for clips or housings to hold the wires, cables, or fluid lines in place.

When used in an aircraft, the composite part **300** may define an confined space which operates in pressurized and unpressurized states at different points in time, depending upon the conditions in which the aircraft is being operated.

In another example depicted in FIG. 3E reinforcement webbing **370A**, **370B** may be wrapped around the structural elements **310A**, **310B** proximate the intersection of the walls **332**, **334** in order to reinforce the joint between the structural elements **310A**, **310B**. The reinforcement webbing **370A**, **370B** may be formed from the same composite material as the structural elements **310**, **320** such that the composite ply material which forms the reinforcement webbing **370A**, **370B** has an elastic modulus which is approximately the same as the elastic modulus of the structural components **310A**, **310B**. The particular number of layers of composite ply material used to wrap structural components **310A**, **310B** is not critical. In some embodiments the vacuum bag **354** may be wrapped with 1-5 layers of composite ply material.

FIG. 5 is a side elevation view of an aircraft **500** having one or more composite parts such as composite part **300** in accordance with another embodiment of the disclosure. One may

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appreciate that composite parts be employed in a wide variety of locations, including the fuselage, wings, empennage, body, and walls of the aircraft **500**. In alternate embodiments, composite parts may be used on other types of structures, vehicles, and platforms, such as motor vehicles, aircraft, maritime vessels, or spacecraft, or other suitable applications.

In this embodiment, the aircraft **500** includes a fuselage **502** including wing assemblies **504**, a tail assembly **506**, and a landing assembly **508**. The aircraft **500** further includes one or more propulsion units **510**, a control system **512** (not visible), and a host of other systems and subsystems that enable proper operation of the aircraft **500**. One should appreciate that composite part may be employed in any suitable portion of the aircraft **500**, such as in a fuselage **502**, wing assemblies **504**, tail assembly **506**, and any other suitable areas of the aircraft **500**. In general, the various components and subsystems of the aircraft **500** may be of known construction and, for the sake of brevity, will not be described in detail herein.

Although the aircraft **500** shown in FIG. 5 is generally representative of a commercial passenger aircraft, including, for example, the **737**, **747**, **757**, **767**, **777**, and **787** models commercially available from The Boeing Company of Chicago, Ill., the inventive apparatus and methods disclosed herein may also be employed in the assembly of virtually any other types of aircraft. More specifically, the teachings of the present disclosure may be applied to the manufacture and assembly of other passenger aircraft, fighter aircraft, cargo aircraft, rotary aircraft, and any other types of manned or unmanned aircraft, including those described, for example, in The Illustrated Encyclopedia of Military Aircraft by Enzo Angelucci, published by Book Sales Publishers, September 2001, and in Jane's All the World's Aircraft published by Jane's Information Group of Coulsdon, Surrey, United Kingdom, which texts are incorporated herein by reference.

In the description and claims, the terms coupled and connected, along with their derivatives, may be used. In particular embodiments, connected may be used to indicate that two or more elements are in direct physical or electrical contact with each other. Coupled may mean that two or more elements are in direct physical or electrical contact. However, coupled may also mean that two or more elements may not be in direct contact with each other, but yet may still cooperate or interact with each other.

Reference in the specification to "one embodiment" or "some embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least an implementation. The appearances of the phrase "in one embodiment" in various places in the specification may or may not be all referring to the same embodiment.

Although embodiments have been described in language specific to structural features and/or methodological acts, it is to be understood that claimed subject matter may not be limited to the specific features or acts described. Rather, the specific features and acts are disclosed as sample forms of implementing the claimed subject matter.

What is claimed is:

1. A method comprising:

joining a first structural element and a second structural element to form a fillet at an intersection of the first structural element and the second structural element; positioning an inflatable radius filler in the fillet; positioning the first structural element, the second structural element, and the inflatable radius filler in a vacuum chamber, wherein the vacuum chamber comprises a first

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vacuum bag, and wherein the inflatable radius filler comprises a second vacuum bag;
 positioning a bag carrier in the second vacuum bag, wherein the bag carrier is shaped to conform to at least a portion of the fillet;
 venting the inflatable radius filler to an environment external to vacuum chamber;
 generating a vacuum in the vacuum chamber; and
 curing the first structural element and the second structural element to form a composite part.

2. The method of claim 1, wherein the inflatable radius filler is in direct contact with the first structural element while the inflatable radius filler is positioned in the fillet.

3. The method of claim 1, wherein the inflatable radius filler is in direct contact with the second structural element while the inflatable radius filler is positioned in the fillet.

4. The method of claim 1, wherein the fillet has a cross-sectional shape that forms a triangle, and wherein the bag carrier comprises a structural component which conforms to at least two sides of the triangle.

5. The method of claim 4, wherein the bag carrier comprises a fabric, and wherein the fabric comprises a resin material such that, after curing, the fabric forms a reinforcement member along a second portion of the fillet.

6. The method of claim 1, wherein generating the vacuum in the vacuum chamber causes the inflatable radius filler to expand within the fillet.

7. The method of claim 1, wherein curing the composite part comprises heating the composite part.

8. The method of claim 1, further comprising removing the inflatable radius filler from the fillet after the first structural element and the second structural element are cured.

9. The method of claim 1, wherein the composite part includes a T-shaped beam.

10. The method of claim 1, further comprising joining the first structural element to a third structural element to form a second fillet at a second intersection of the first structural element and the third structural element.

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11. The method of claim 10, wherein the composite part includes the third structural element.

12. The method of claim 11, wherein the composite part includes an I-shaped beam.

13. The method of claim 10, further comprising:
 positioning a second inflatable radius filler in the second fillet;
 positioning the second inflatable radius filler and the third structural element in the vacuum chamber while the first structural element is in the vacuum chamber;
 venting the second inflatable radius filler to the environment external to vacuum chamber; and
 curing the third structural element concurrently with the curing of the first structural element.

14. The method of claim 1, wherein the first structural element comprises a first structural component and a second structural component, and wherein the fillet is formed by the first structural component, the second structural component, and the second structural element.

15. The method of claim 1, further comprising wrapping reinforcement webbing around the first structural element.

16. The method of claim 15, wherein the reinforcement webbing and first structural element comprise a composite material.

17. The method of claim 15, wherein the reinforcement webbing has a first elastic modulus, wherein the first structural element has a second elastic modulus, and wherein the first elastic modulus and the second elastic modulus are approximately the same.

18. The method of claim 15, wherein the reinforcement webbing is wrapped around the first structural element at least two times.

19. The method of claim 1, further comprising forming a part for an airplane, the part comprising the composite part.

20. The method of claim 1, wherein the bag carrier comprises a metal bracket that conforms to the shape of the fillet.

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